

**Referee comments on the paper submitted to Geoscientific Model Development (GMD) “Evaluation of Monte Carlo tools for high energy atmospheric physics” by Casper Rutjes, David Sarria, Alexander B. Skeltved, Alejandro Luque, Gabriel Diniz, Nikolai Østgaard, and Ute Ebert**

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The paper concern problem of code verification, i.e., it answers to the questions is a code error-free, well engineered, meet specifications, are the test result compatible with analogical codes, and so on. Verification will not ensure that the system is useful for understanding the physical phenomenon under investigation and will not be crucial to choose the theory that explains experimental measurements in the best way. The procedures trying to answer the question will be the implementation of a code useful for understanding physics has an overall name of the code validation. Validation is the process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are accurate representations of the real world (Dept. of Defence doc., 2008).

By model we mean a complete probability statement of what currently supposed to be known a priori about the mode of generation of data and of uncertainty about the parameters (Box, 1984). These definitions emphasized that simulations should confront the experimental data! The model and simulations should be architecture in a way to allow direct comparisons of experimental data and model results. Sure, the attention should be made on proper selection and quality control of experimental data as well.

The most difficult and most important part of the model validation is the comparison of competitive hypotheses and decision making on the nature of the investigated physical phenomenon. The new emerging field of high-energy atmospheric physics (HEAP) includes 2 main physical phenomena: Terrestrial Gamma Flashes (TGFs) - brief burst of gamma radiation (sometimes also electrons and positrons) registered by the orbiting gamma ray observatories in the space and Thunderstorm ground enhancements (TGEs) - the prolonged particle fluxes registered on the ground level. There are an alternative name “Gamma glows” introduced by Joe Dwyer, but this name does not fit very well because on the ground we detect as well fluxes of electrons and neutrons. Both TGFs and TGEs are related to the thunderstorms and lightnings: TGEs - by directly detecting electric field and lightning occurrences above the detector site; TGFs by making rather complicated synchronization with worldwide lightning detecting networks.

The central engine initiated TGF and TGE is believed to be the Relativistic Runaway Electron avalanches (RREA) accelerated seed electrons in the terrestrial atmosphere up to 30-40 MeV. The *in situ* observation of numerous RREAs during strong thunderstorms on Aragats and first simultaneous measurements of TGE electrons and gamma ray energy spectra proved that RREA is a robust and realistic mechanism for electron acceleration. Detailed measurements of the gamma ray energy spectra by large NaI spectrometers on Aragats allow to reliably extending energy range of the “thunderstorm” gamma rays up to 100 MeV due to another “thunderstorm” gamma ray production mechanism - MOdification of the electron energy Spectrum (MOS).

Thus, the RREA mechanism operating in the lower and upper atmosphere generates 2 phenomena – the fluxes of electrons, gamma rays and neutrons on the Earth’s surface, i.e. TGEs; and gamma rays and sometimes also electron/positrons in the space observed by the orbiting gamma ray observatories from the Earth’s direction (TGFs).

TGFs and TGEs share many common features, as they are results of RREA. The drastic time difference (minutes for TGE and hundred of microseconds for TGF) is not essential because prolonged TGEs are nothing more than a superposition of the short nanosecond scale avalanches, which Aragats group has named Extensive cloud showers (ECS) and Alex Gurevich et. al., Micro runaway breakdown – MRB).

## **2. Available Validation data from detected TGEs on Aragats**

The “natural electron accelerator” is operating in thunderclouds above the research station Aragats of Yerevan Physics Institute (Chilingarian, Hovsepyan and Mnatsakanyan, 2016) at an altitude of 3200 m on the plateau near a large lake. Numerous particle detectors and field meters are located in three experimental halls as well as outdoors; the facilities are operated all year round. All the relevant information is being gathered, including data on particle fluxes, fields, lightning occurrences, and meteorological conditions and is available via the multivariate visualization software ADEI on the Web page of the Cosmic Ray Division (CRD) of the Yerevan Physics Institute <http://adei.crd.yerphi.am/adei>. Several published papers provide information that can be directly compared with simulations. We present numerous energy spectra, intensities of gamma ray and electron fluxes, disturbances of electric field during TGEs; relations of lightnings and particle fluxes; relations of neutron and gamma ray fluxes and many others. Numerical data and plots on following research topics can be downloaded from the site:

- Cold Runaway or/and electron acceleration in the electric fields of the thundercloud. TGE research do not support the first hypothesis; during large TGEs lightning activity is suppressed, lightnings stop particle flux not initiate it (Chilingarian et al, 2011, Hovsepyan and Kozliner , 2015);
- *In situ* measurements of RREA, density and space distribution of avalanches, etc (Chilingarian et al., 2011);
- Estimated phenomenological parameters of the RREA (Chilingaria, Mailyan and Vanyan, 2012);
- TGEs and Charge structure of Thundercloud (Chilingarian & Mkrtchyan, 2012, Chilingarian, 2014);
- Energy spectra of the TGE gamma rays (Chilingarian et all., 2013, Chilingarian, Hovsyapyan and Kozliner, 2016).
- Relation of TGEs and Lightnings, Chilingarian et all, 2015, Chilingarian, Chilingaryan and Reymers, 2015).

### 3. Conclusion

In Introduction section should be corrected the definition of HEAP including references to TGE phenomenon.

Add recommendations on the code validation.

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